research review

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daytime aurora

DR. S. SILVERMAN, Upper Atmosphere Physics Laboratory, AFCRL

The aurora has defied satisfactory explanation. One popular hypothesis is that it results from a dumping of particles from the earth's outer radiation belt into the upper atmosphere. But the large number of particles needed to sustain the aurora would quickly deplete the reservoir of particles within the belt. Furthermore, the aurora mechanism would require particles of higher energies than those found in the belt.

Particles directly from the sun--those comprising the solar winds and sometimes known as solar plasmas--could provide fluxes of sufficient energy, but the earth's magnetic field is a barrier to their direct entry into the atmosphere. Another postulated mechanism is one whereby solar plasma enters the earth's atmosphere from the "back door"--that is, the plasma returns to the earth along the extended lines of magnetic force in the long tail of the field on the night side of the earth.

Because Air Force communications and sensors used for detection, reconnaissance, and surveillance are sometimes strongly affected by auroral absorption, scattering, and reflection, the aurora is of great interest to AFCRL. Several separate AFCRL groups are investigating various aspects of it. One AFCRL group, in March 1965, launched two instrumented rockets from Fort Churchill, Canada, into the aurora to measure ion concentrations. Another AFCRL group, jointly with Northeastern University scientists, recently reported on a rocket experiment conducted last summer to optically observe the elusive daytime aurora.

One problem in measuring the daytime aurora optically is, very simply, that of knowing when the aurora is present. Because it can not be seen optically from the ground (except for detection of a few spectral lines), studies of the daytime aurora have been restricted almost entirely to investigations by radio techniques. Statistical studies indicate some correlation between the radio and visual nighttime aurora, but the correspondence is certainly not one to one. A second problem, of particular importance for rocket measurements, arises from the fact that the aurora is normally quite limited in spatial extent, and exhibits both rapid spatial movements and rapid intensity fluctuations. Consequently, a rocket fired at an aurora may find the aurora no longer there when it reaches auroral altitudes.

Because of the many uncertainties as to whether or not the aurora would be present

at the time of the firing, all available knowledge of the aurora and auroral processes went into the establishment of criteria for launching. Among these were: 1) the existence of moderate-to-strong magnetic activity; 2) riometer absorption greater than 0.5 db; 3) increased ionospheric absorption; and 4) the presence of radar auroral echoes. These criteria were met on the morning of 18 July 1964, and the launching took place at 0622 CST.

The instrument flown was a one-meter Ebert spectrophotometer with fixed slits set for a resolution of 11 angstroms and scanning the wave-length range 4000 to 5900 angstroms in seven seconds. The instrumental field of view was directed along the longitudinal axis of the rocket and viewed the sky through an opening exposed by the ejection of the nose-cone tip. A 14-inch baffle and sun shade were mounted in front of the input slit to minimize the sunlight scattered into the instrument.

This same instrumentation had been used in an experiment conducted by AFCRL six months earlier from the White Sands Missile Range in New Mexico to measure day airflow. Data from this earlier experiment proved to be very important in helping to define the upper border of the daytime aurora at Fort Churchill. In the earlier White Sands flight, only one line--5577 angstroms [OI]--was clearly identified as the day airglow line.

In the Fort Churchill flight, two lines were unambiguously observed--5577 angstroms and 4278 angstroms (N_2+). The highest altitude at which the 4278-angstrom line was recorded was taken to be the upper limits of the daytime aurora. This limit was between 113 and 123 km, an altitude typical of the upper limit of the nighttime aurora. The lower border of the daytime aurora was not determined.

The flight also gave additional data on day airglow. Above 123 km, the relative intensities of the 5577-angstrom day airglow line at both Fort Churchill and White Sands were comparable. The intensity of the line, however, fell off more rapidly with altitudes at Churchill than at White Sands, indicating--possibly--a broader airglow layer in more southerly latitudes. ★

research review
OFFICE OF AEROSPACE RESEARCH

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JACOB SEIDEN
Editor

mechanism for twinkling stars

UPPER ATMOSPHERE PHYSICS LABORATORY, AFCRL

When an unsuspected phenomenon is uncovered during the course of an experiment, it becomes necessary to somehow account for the novel effect. The explanation sometimes provides insight into physical processes completely unrelated to the initial experiment.

This was essentially the outcome of an experiment set up to examine the relativistic (as against the well-known classical) Doppler effect under conditions of extremely rapid phase-path changes formulated by Einstein. The effect was not observed due to the limitations of the apparatus. Instead, Dr. Kurt Toman of AFCRL, who conducted the experiment, observed a phenomenon characteristic of scintillation, and this led him to postulate a mechanism for the observed scintillation effect. (Scintillation is merely the randomly varying intensity of electromagnetic energy from stars and satellites as observed from the ground, the best-known manifestations of which are twinkling stars.)

In the relativistic Doppler experiment, under conditions where the phase path of an electromagnetic wave can be changed rapidly, Toman wanted to determine whether or not a shift in frequency could be observed. How is it possible in the laboratory to achieve these high accelerations? It can be done rather simply with mirrors. Essentially, all that is needed is a light source, a flat rotating mirror and a detector.

As the flat mirror is rotated, the path length between source and the point of reflection on the mirror varies. In the actual experiment, the flat surfaces of a hexagonal piece of stainless steel were polished to a flatness of about a tenth of a wave length. The shaft of this 6-sided piece was inserted into an air turbine which provided the rotation. These mirrors could be made to rotate at a rate up to 350,000 rpm.

To better understand the observed scintillation effect, the apparatus should be described with somewhat more precision. Light from a monochromatic source is passed through an achromatic lens, an adjustable slit and a fixed slit, and an interference filter 70A wide to the mirror. The reflected light passes through a Fabry-Perot interferometer and a camera lens to a photographic plate. A photomultiplier tube could be substituted for the photographic plate.

The resultant image is an interference ring system. As the experiment was initially planned, these rings would undergo a profile broadening or a profile shift in consequence of the Doppler effect. As it turned out, neither was observed--nor was it expected that they would be, simply because certain compromises in mirror size and rotation rate were made in the design of the apparatus that precluded the occurrence of these effects. Even though it was clear that the original objective of the experiment could not be met, the apparatus was placed in operation to evaluate its design.

Observing the ring system visually, AFCRL scientists were surprised to find an apparent instability in the appearance of the ring system. The observed phenomenon had the characteristics of scintillation. The brightness seemed to vary independently from point to point along the circumference of a ring. Moreover, the scintillation rate seemed to remain the same at high and low rotation rates of the mirror surfaces. Light flashes that seemed to extend beyond the width of

the luminous rings were also observed.

Microdensitometer tracings of photographic plates showed this scintillation to be a real rather than an illusory phenomenon. The most puzzling feature was that the fluctuations seemed to vary randomly. It was found that the scintillations were more pronounced under conditions of low light intensity. The light flashes that extended beyond the width of the luminous rings were of special interest, and a number of controlled experiments involving photographic and photoelectric detection were devoted to these alone.

Air turbulence associated with the rotating element was considered as a possible cause of the scintillation, as were instabilities in the rate of rotation. Neither of these were found to be the cause. Although the precision polishing of the mirrors to within a tenth of the wave length of the Hg 198 light source (5460.75 A) would seem to rule out the mirror imperfections as a source of the scintillation, the prospect of mirror curvature was nevertheless examined rigorously. As a result of this analysis, the mirrors, in fact, were identified as the most probable cause of the scintillations. The mechanism postulated for this scintillation is acceleration along the ray path caused by possible curvatures within the mirror surfaces.

This postulate has a direct bearing on optical star, radio star and satellite signals that are transmitted to the observer through a time-varying, irregular medium--that is, the atmosphere. Certain scintillation processes could be synonymous with extremely fast accelerations along a ray path due to effective local curvature distributions in the random medium. Certain scintillation mechanisms could be explained in part on the basis of the effect noted in the AFCRL experiment. ★

SUCCESSFUL RANGE OPERATIONS AT CRR

Calendar year 1964 was, for the Churchill Research Range (CRR) at Fort Churchill, Manitoba, its most active and successful year of operation. During that period, CRR launched 103 rockets using 475:10 range hours. A total of 150 have been fired since the range opened under OAR management. Of the rockets fired in 1964, 34 were for NASA with 241:40 range hours, 4 for AFCRL with 21:30 range hours, 17 for Canadian agencies with 165:50 range hours, and 48 were fired for the 4th Weather Group with 46:10 range hours. Of the total 475:10 range hours expended, only 10 hours and 48 minutes could be charged to CRR as down time on any of its systems. Of the 52 aborts in 1964, only two were attributed to a "no go" condition of the range. Most aborts were caused by weather. In addition to these foregoing statistics, 150 hours of range time (radar only) were expended in the Navy balloon "SKYHOOK" program.

Two of the most outstanding feats of the year were the first Javelin-Nike Apache companion firings which were performed for NASA, and the nearly simultaneous launch of the Black Brant II and Nike Cajun for AFCRL. Both series were a spectacular success and a crowning achievement for the range.

During the month of December, eight Arcasondes were flown for the Meteorological Rocket Network. Four tests were cancelled as a result of unsatisfactory weather conditions. All rockets performed well. ★

electromagnetic effects on plasma media

MICROWAVE PHYSICS LAB., AFCRL

A plasma medium may be altered when an electromagnetic wave propagates through it. Just how much it is altered and in what way depends on the power level of the signal, the frequency, and the plasma density. But this was previously understood only in a qualitative way. Rigorous analytical studies of physical processes had not been made until recently. In highly significant

research conducted by Robert Papa of AFCRL, a deeper understanding of electromagnetic-plasma relationships has been uncovered. These theoretical investigations involve the simultaneous solution of the Boltzmann equation and Maxwell's field equations.

Plasma research is of Air Force interest not only from the standpoint of communicating through the ionized layer surrounding a space vehicle on re-entry, but also with respect to simple communications between the earth and satellites in which the signal must pass through the plasma layer of the ionosphere.

Papa's analysis is concerned with the response of plasma media to radio-frequency waves of moderate and high-field intensities under a wide range of plasma parameters. Unlike ordinary dielectrics, the effective dielectric constant of a plasma can be altered by field strengths of relatively moderate intensity. Many things affect the reflection and transmission coefficients of an inhomogeneous plasma: 1) scale of electron-density gradients; 2) scale of electron-temperature gradients; 3) thickness of the medium; 4) initial degree of ionization; and 5) relative magnitudes of the electron-neutral, electron-ion and electron-electron collision frequencies. Theoretical results show that, for a plasma corresponding to high-temperature air (5000^{o} K) subject to X-band radiation, 10 to 20 per cent changes in reflection and transmission coefficient will occur as the incident field intensity is increased up to a certain critical field intensity. Above this critical field intensity (which is a function of the frequency of the incident wave), the electron temperature, under steady-state conditions, will become very large with a consequent large increase in electron density. This will result in a sharp drop in transmitted field intensity and a sharp increase in reflected energy.

One interesting result of the analysis is that, at moderate field intensities, the boundaries defining plasma media can be altered in such a way that an initial electron-density profile will appear to move toward the perturbing source of electromagnetic radiation.

For the case of a monochromatic, transverse plane wave incident upon an inhomogeneous plasma which varies slowly in space and time, the coupled system of Maxwell's equations and the moments of the Boltzmann equation may be solved numerically. The results of these studies show that: 1) even though the electron-energy relaxation time is much longer than the period of the electromagnetic field, the plasma temperature may not reach a steady state because the boundaries defining the plasma medium may move under the perturbing influence of the electromagnetic wave; 2) the wave field in the plasma will not remain monochromatic even though the incident wave is monochromatic because the electrical conductivity is time-varying; 3) the time scales for electron-density and electron-temperature changes may be vastly different, and can be drastically changed as the incident flux level is changed.

The nonlinear response of plasma media to high-power radio-frequency fields is being extended to include the effects of dc magnetic fields, which cause the propagation characteristics of plasmas to become anisotropic. When a radio-frequency wave is propagating in a plasma in dc magnetic field, the radio-frequency wave splits into three distinct modes: a right circularly polarized wave, a left circularly polarized wave, and a longitudinal wave. At sufficient power levels, these modes will become coupled; that is, the propagation characteristics of one mode depend upon the presence of the other modes.

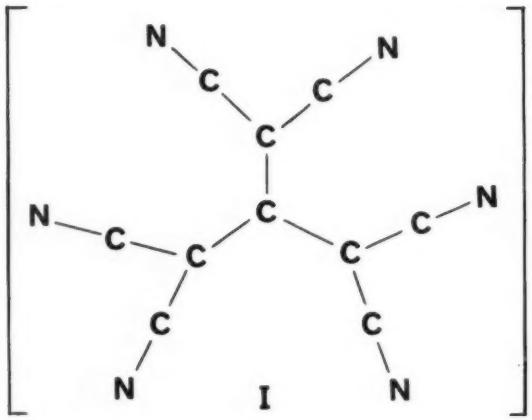
The nature and extent of the mode coupling under a wide range of plasma parameters are being determined--even for the case where the electron velocity distribution function is non-Maxwellian. It is well known that the effective dielectric constant of a plasma depends upon the electron velocity distribution function. Most calculations assume the electron distribution function is Maxwellian. However, in the nonlinear regime, the electron distribution function may become non-Maxwellian. Present studies are aimed at learning what effect non-Maxwellian distribution functions will have on the propagation characteristics of a radio-frequency wave. ★

PROPELLER PITCH AND MOLECULAR TILT

DR. A. J. MATUSZKO, Directorate of Chemical Sciences, AFOSR

The molecular and crystal structures of several organic compounds with unusual geometry and electronic structure have been elucidated by the application of X-ray diffraction techniques. The basic study done at the University of California at Los Angeles, under the direction of Dr. Kenneth Trueblood, was supported by the Directorate of Chemical Sciences, AFOSR.

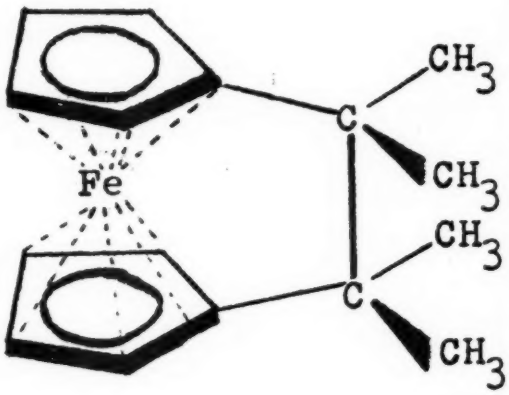
Among the compounds studied by Dr. Trueblood and his co-workers was the anion of the unusually strong acid, hexacyanoisobutene



I

(I). This negatively charged molecule was found to have a novel propeller shape, the three Y-shaped arms which radiate symmetrically from the central carbon atom being tipped about 24° out of planarity. Simple "resonance" considerations had suggested that this anion would be planar; the fact that it is not provides more data for assessing the relative importance of repulsive interactions between nonbonded atoms within a molecule (which tend to make the molecule nonplanar) and of π-overlap (which favors planarity). In this substance, the repulsive interactions predominate, although actually the loss in overlap energy is not great. The final configuration is, of course, the compromise in which energy has been minimized.

Another interesting compound studied was 1, 1'-(tetramethylethylene)-ferrocene (II). Unsubstituted ferrocene, which is one of the



II

most stable organometallic compounds known, has a structure consisting of a central atom of iron "sandwiched" between two cyclopentadiene rings positioned in parallel planes to one another (the characteristic pi bonds perpendicular to the plane of the cyclopentadienyl rings are what hold the iron inside the sandwich). Due to the shortness of the two-carbon bridge in Compound II, one would expect the cyclopentadienyl rings to be appreciably tilted relative to one another. The UCLA scientists found that the bridge does force these rings about 25° out of parallel. In the unsubstituted ferrocene molecule, the carbon atoms are staggered, i.e., one ring is rotated 36° relative to the other. The bridge prevents this rotation in II, and the rings are only 9° from the

eclipsed position. (In the eclipsed position, one ring would be superimposed upon the other.) The precise conformation adopted by this strained molecule provides data for assessing the relative importance of different types of interatomic interactions.

In the crystal, the tilted molecules of II are arranged as shown in Fig. 1. Those structures drawn in heavy lines project out in front of the plane of the paper.

Structure studies, such as the ones done by Dr. Trueblood, will shed new light on how the spatial arrangements of atoms or groups of atoms in a molecule affect molecular stability. This information will be useful to the Air Force in understanding and predicting the behavior of newly synthesized compounds for materials applications. ★

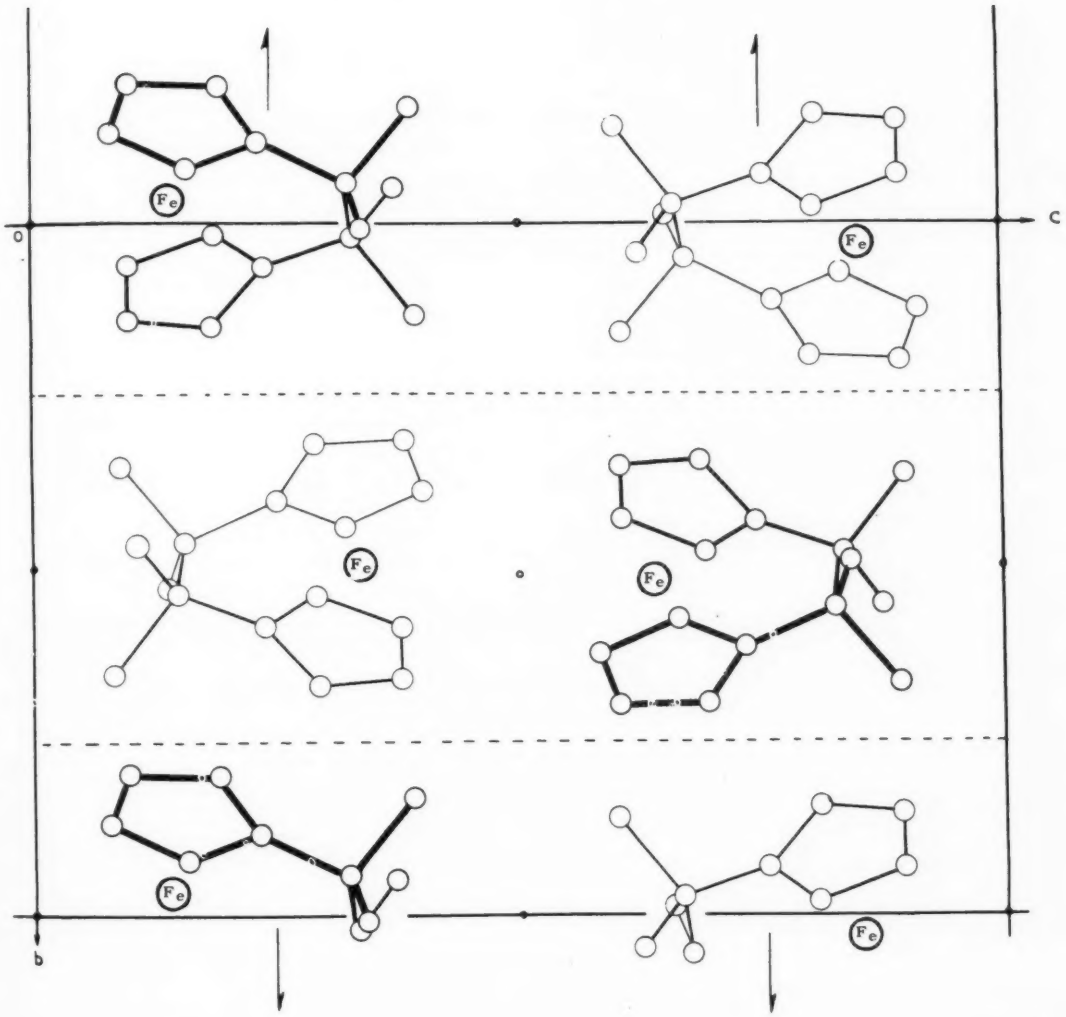


FIG. 1 Arrangement of 1, 1'-(tetramethylethyl)-ferrocene molecules in a crystal (unit cell [100] projection).

EXPERIMENTAL CONFIRMATION OF MAJOR CHANGE OF DEFECT TYPE WITH TEMPERATURE AND COMPOSITION IN IONIC SOLIDS

LT COL R. W. CONNERS, Directorate of Physical Sciences, AFOSR

In recent papers, (1)(2) Rustum Roy and A. M. Diness, Pennsylvania State University, supported in part by the AFOSR Solid State Sciences Division, commented on the rarity of actual determinations of the point defects present in common ionic solids. In the vast majority of cases, the type of defect is assumed on the basis of analogy with previously supposedly well-known cases, or on the basis of a circular argument resulting from the expected property change due to the assumed defect.

During the last few years, Roy et al have attempted to carry out a few reasonably precise definitions of the point defects present in simple-structure ionic solids. An essentially "pure interstitial" model was confirmed by Short and Roy (3) and Roy and Roy (4) for the fluorite structure crystalline solutions with YF_3 and the rare-earth fluorides. In the sodium-chloride structure oxides, Stubican and Roy (5) again determined an essentially "pure cation vacancy" model in the Al^{3+} substitution in MgO. The third family of defects studied was the anion vacancy, and the systems chosen were the classical ones based on the fluorite structure oxides related to ZrO_2 and ThO_2. This article reports briefly, for what is believed to be the first time, on the experimental confirmation of a mixture of defect types in one of these systems. Furthermore, Roy et al have also experimentally observed the change of this defect type with temperature of equilibration, and its dependence on concentration of defect.

The system, CaO-ZrO_2, contains the prime examples of the "doped zirconia" crystalline solutions which are said to be of the "pure" anion vacancy type. (6) In an earlier study of the thermodynamic "stability" of CaO in the ZrO_2-CaO crystalline solution, Roy et al redetermined the phase equilibria in the system (7), and prepared the several compositions across the cubic crystalline solution field and equilibrated these at various temperatures. Thus prepared, the solid phases are then quenched at about $1000^{\circ}C$/sec. as well-crystallized, partially sintered powders. In order to determine the point-defect character, it is necessary to determine the lattice parameters and the "bulk" density independently, to calculate the densities required by various models, and compare the observed values with those calculated for these various models.

The X-ray measurements were made on the quenched microcrystalline powders. Diffractometer traces were run at $1/4^{\circ}$ per minute on a Norelco diffractometer, using 4° slits and a Ni filter in the high angle region, and were corrected by means of an external silicon standard. These peak position values were indexed and then fitted to a least squares curve of 2θ versus $\cos^2\theta/\sin\theta$ by means of a simple FORTRAN program run on an IBM 7074 computer. The results were expressed as a_o values extrapolated to 180° 2θ. The parameters thus obtained from the X-ray data were used to calculate the densities of each composition studied in the Fluorite field, assuming either a cation interstitial model or an anion vacancy model. These calculated values of the density were compared with those pycnometrically measured on equilibrated one-half gram to one-gram pellets in a 2ml. vessel. The high-density liquid employed in these measurements was bromoform. It was found that it was essential to degas the pycnometer containing the sample covered with bromoform by evacuation before weighing the entire assembly.

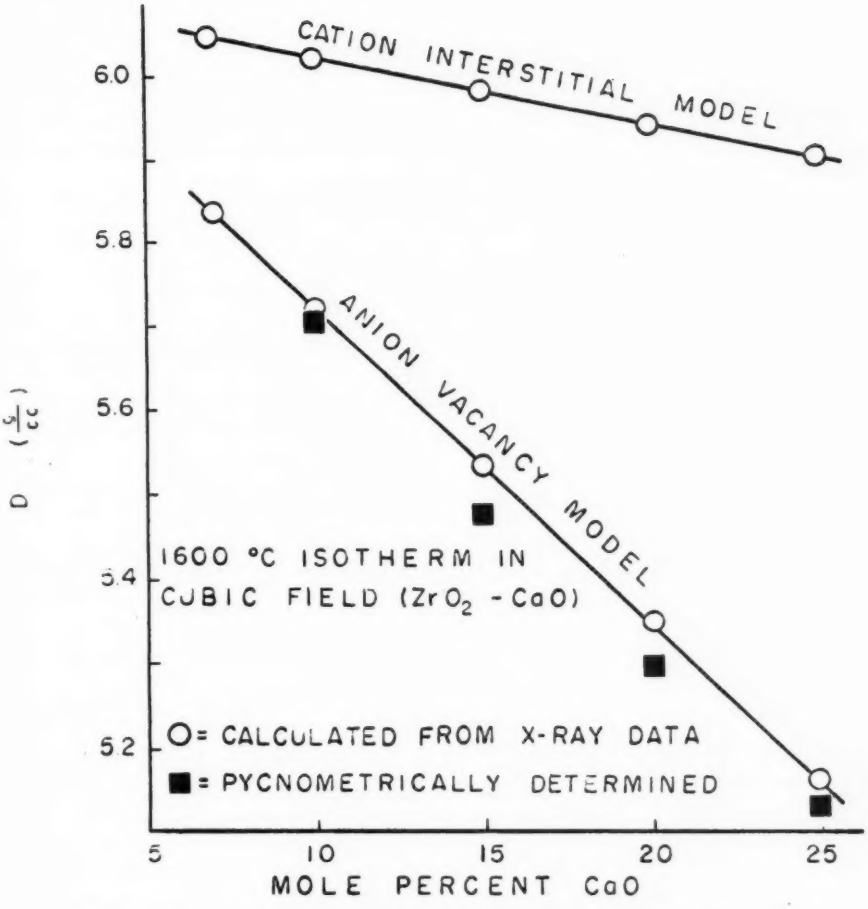


FIG. 1 Comparison of densities determined by X-ray and pycnometric methods for CaO-ZrO_2 crystalline solutions quenched from 1600°C.

The results obtained for two series of phases, equilibrated at 1800° C and 1600° C, respectively, are shown in Figs. 1 and 2. In the 1600° C set, the measurements confirm the classically accepted model of an effectively "pure" anion vacancy defect for that material. At 1800° C, however, it is seen that in the low CaO concentration region (up to at least 15 mole %), the measured densities point to a predominantly interstitial cation model. When the results were first obtained, Roy et al attempted to search for every error in the density measurement. All the systematic errors that are normally introduced in such measurements lower the density (e.g., porosity, air films attached to surfaces, mixtures with probable second phases). The composition of the reacted crystalline solutions was checked by X-ray fluorescence methods and found to be on composition within experimental error. Analysis of several samples of precious metals (especially platinum and rhodium) by emission spectroscopy showed that con-

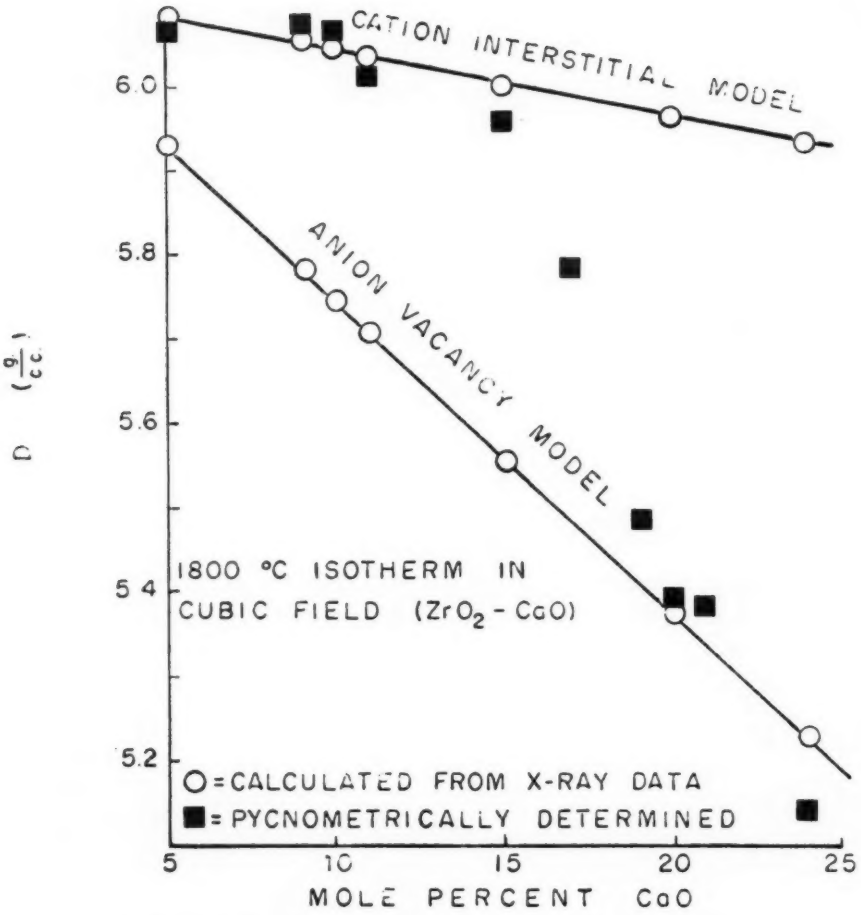


FIG. 2 Comparison of densities determined by X-ray and pycnometric methods for CaO-ZrO_2 crystalline solutions quenched from 1800°C.

tamination with these metals was not the cause of the higher densities.

Confirmation of the existence of the difference in defect state at 1600° C and 1800° C was also sought in precise lattice parameter and relative intensity measurements in the X-ray powder patterns. These results further confirm the change in structure (= defect type) as reflected in both the lattice parameters and the relative intensities. The lattice parameter of the 10 mole % phase changes from 5.130 (vacancy) to 5.123 (interstitial), and for the 15 mole % from 5.144 to 5.134. The relative intensities for the 10 mole % solution in the vacancy "polymorph" are $I_{422} = 62$, $I_{511} = 100$, $I_{440} = 21$, while in the interstitial "polymorph" they are $I_{422} = 100$, $I_{511} = 100$, $I_{440} = 50$. Similar data were obtained on the 15 mole % member.

Clearly, therefore, Roy et al have an example here of the change of point-defect type from predominantly interstitial cations at 1800° C to predominantly anion vacancies at 1600° C. Several facts are of further interest. First, at 1800° C, the more concentrated (greater than 20 mole %) solutions

are still predominantly anion vacant. It was also observed that samples of 87 mole % ZrO_2 and 81 mole % ZrO_2 had densities corresponding to approximately equal amounts of vacancies and interstitials. Likewise, similar intermediate types must be the equilibrium forms at some temperature between 1600 and 1800° C; confirmatory data was obtained on such equilibrium forms at 1750° C.

At this stage of the work, the results have not defined the equilibrium concentration of defects at any temperature with great precision, since Roy et al cannot be sure that the "quenching" perfectly reproduces the high-temperature defect character. From these data, it is apparent that physical measurements on wide band gap materials should be preceded by characterization procedures which include prima facie studies of point-defect content.

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\# *The term, "pure," is used advisedly, suggesting here that one type of defect predominates to such an extent that the concentrations of the other defects cannot be detected by the methods used.*

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FY-65 ALLOCATIONS OF AIR FORCE INDEPENDENT RESEARCH FUND ANNOUNCED

RESEARCH INFORMATION OFFICE, AFCRL

The selection of 15 special AFCRL research projects for funding by the Air Force In-House Laboratories Independent Research Fund for FY-65 has been announced. This special category of resources, established by the Air Force in 1962, may be spent at the discretion of the Laboratory Commander to support urgent and timely scientific investigations. The FY-65 AFCRL allocation of funds in this category was $2 million.

The Independent Research Fund affords flexibility in planning research programs, and permits the implementation of new and significant investigations with a minimum of delay. No prior approval from a higher headquarters is required in the use of these resources.

This funding category is in addition to the normal AFCRL budget which, in 1965, will total about $55 million for salaries, equipment, and contract research. Expenditures made under the regular budget are subject to established review procedures.

The 15 approved projects were selected by the Commander from among 35 special research proposals submitted by AFCRL scientists, and will provide for:

1) The development and construction of a fine-resolution millimeter-wave antenna array to be located at L. G. Hanscom Field. Principal investigator: Dr. Allan Schell.

2) A series of theoretical studies leading to an understanding of EM radiation in rotating systems, with results contributing to the fundamental knowledge of EM radiation phenomena. Principal investigator: Dr. E. Jan Post.

3) Extending the world-wide coverage capability of a network for collecting ionospheric data from satellites. Principal investigator: John P. Mullen.

4) A combined electron-microscope X-ray microanalyzer for analysis of micrometeoritic particles. Principal investigator: Dr. Robert K. Soberman.

5) Implementing solar-flare forecasting techniques, fundamental to the Space Forecasting Workshop Program. Principal investigator: Dr. Fred W. Ward, Jr.

6) The installation of a Videx Transmission and Display System for transmitting solar photographs from AFCRL's Sacramento Peak Solar Observatory in New Mexico, to AFCRL in Bedford. Principal investigator: Dr. Fred Ward, Jr.

7) Developing an extended lifetime cryogenic radiometer for satellite use to operate in the 15-micron region. Principal investigator: Charles V. Cuniff.

8) The modification of a high-resolution spectrograph for investigating laser materials and laser radiation in the visible and ultraviolet emission regions. Principal investigator: Rudolph A. Bradbury.

9) The development of a standard for low-light-level absolute calibrations in the visible spectrum. This definitive standard will serve as the norm for calibrating systems used in the study of aurora and airglow. Principal investigator: Dr. Gonzalo J. Hernandez.

10) The design, construction, and integration of five complete IQSY sounding-rocket pay loads to be used in the study of the D and E regions of the ionosphere. Principal investigator: Rita C. Sagalyn.

11) A program of analytical studies of the infrared spectra of selected solids subjected to high pressures from an atomistic point of view. Principal investigator: Dr. Johannes N. Plendl.

12) The conduct of atmospheric-turbulence studies in the 100 to 200 thousand foot altitude region, and the development of special rocket pay loads to be used in these investigations. Principal investigator: Bernhard Lettau.

13) The purchase of a real-time radar Doppler processor, and its development for use in Doppler weather radar research. Principal investigator: Dr. David Atlas.

14) The development and in-house construction of a novel interferometer, and techniques for reducing existing sequential processes for computer analysis of interferograms. Principal investigator: Dr. George A. Vanasse.

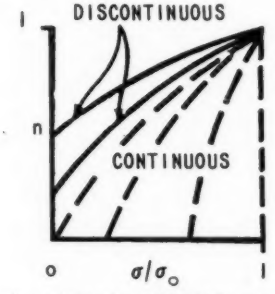
15) Investigations of radiative fluxes in the atmosphere, and their correlation with atmospheric temperature, pressure, humidity, and composition profiles. Principal investigator: Russell Walker. ★

VARIABLE CONDUCTIVITY MFD COUETTE FLOW

K. R. CRAMER
Thermomechanics Research Laboratory, ARL

A considerable portion of the theoretical literature in magnetofluid-dynamics contains the simplifying assumption that the electrical conductivity is uniform throughout the fluid. MFD experiments with high-temperature conducting gases usually require protective cooling of the models and, since the conductivity is temperature-dependent, it may vary considerably through the boundary-layer region. The fluid may even be nonconducting near a highly cooled surface. Proper comparison of experiment with theory requires a theory that includes an accurate conductivity-temperature relation.

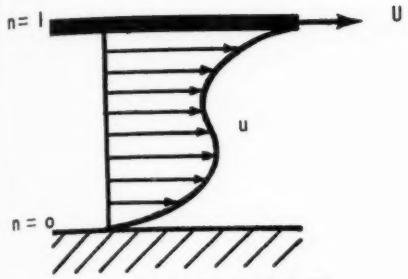
A theoretical study of a simple MFD case was conducted wherein a number of conductivity distributions were assumed to estimate their importance and effect on the fluid dynamic variables. Specifically, Couette flow of a conducting fluid subjected to magnetic and electrical fields was examined for several continuous and discontinuous electrical conductivity profiles (Fig. a) having a



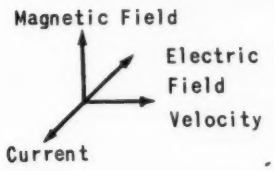
a) TYPICAL CONDUCTIVITY PROFILES

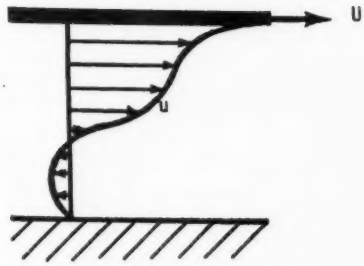
general polynomial dependence on the transverse distance of the form

$$\frac{\sigma}{\sigma_0} = A + B\eta^n$$



b) S-SHAPED VELOCITY PROFILE





c) DOUBLE S-SHAPED VELOCITY PROFILE

The discontinuous profiles provided a description of flow where the fluid is nonconducting near the stationary surface. The velocity profiles, surface shears, and flow rates were calculated for small magnetic Reynolds numbers, and one example included a transverse electric field and a longitudinal pressure gradient.

Any reduction of the conductivity produces a smaller MFD retardation. Consequently, calculations based on a constant conductivity underestimate the fixed surface shear and flow rate, and overestimate the moving surface shear. Stronger magnetic and electrical fields magnify the influence of nonuniform conductivity.

Major differences in the fixed surface shear are produced by changing the exponent of the conductivity profile and, for a given profile, only minor differences occur when less than a fourth of the fluid is nonconducting. The following table contains sample percentage changes compared to the commonly assumed constant conductivity for flow without a pressure gradient or electrical field.

For uniformly conducting flow, the combined effect of the external electrical field and pressure gradient can produce S-shaped velocity profiles when they provide pumping in the direction of the moving plate. (Fig. b.) The S shape occurs because the MFD retardation is less in the lower-velocity region, whereas the combined pumping is uniform across the passage. When a portion of the passage is nonconducting, and the flow has a sufficiently large adverse pressure gradient, a double S-shape velocity profile (Fig. c) with back flow near the fixed plate can be produced since the magnetic and electric fields are ineffective in the nonconducting region. A correctly oriented external electrical field can increase the pressure required to reverse the flow near the fixed plate even when a large portion of the fluid is nonconducting, since the velocity and

	n = 0		n = 1		n = 2		
	M = 2	M = 4	M = 2	M = 4	M = 2	M = 4	
Fixed surface shear			+ 31	+ 135	+ 48	+ 245	Nonconducting fraction
Moving surface shear			- 9	- 7	- 16	- 14	0
Flow Rate			+ 9	+ 18	+ 15	+ 36	
Fixed surface shear	+ 9	+ 38	+ 34	+ 148	+ 49	+ 269	
Moving surface shear	- 1	+ 0	- 9	- 7	- 16	- 14	1/4
Flow Rate	+ 1	0	+ 9	+ 18	+ 15	+ 36	

shear are continuous across the passage.

An accurate conductivity profile was computed for a liquid sodium flow with the fixed plate at a higher temperature than the moving plate to provide a continuous profile for comparison with the assumed profiles. The computed profile agreed well with the assumed parabolic profile.

Finally, since major errors may occur from the assumption of uniform electrical conductivity, experimental results and theoretical predictions must include a detailed specification of the conductivity distribution when sizable temperature gradients exist in MFD flow at moderate Hartmann numbers.

The analysis and complete results are contained in ARL 65-13. ★

AFCRL REPORTS INCREASED BALLOON R&D ACTIVITY IN 1964

T.J.DANAHER, Aerospace Instrumentation Lab., AFCRL

The Air Force Cambridge Research Laboratories, in 1964, launched 130 large research balloons, reflecting a steady growth both in number of flights and in capability. The year saw not only a marked advance in balloon development, but also an increased diversity in the kinds of research experiments carried aloft as balloon pay loads. AFCRL is the nation's largest user and developer of research balloons.

Balloons are regularly taking scientific instruments up to about 27 miles. At this altitude, only a fraction of a per cent of the earth's atmosphere remains, and a clear view of the moon, planets and stars can be obtained. Among the highlights of the AFCRL 1964 balloon program were:

1) Flights made in February and October 1964 for Johns Hopkins University in which a 30-cm aperture telescope was carried to an altitude of more than 80,000 feet to measure the water vapor in the Venus atmosphere and the reflectivity of the Venus cloud layer.

2) A series of photoreconnaissance experiments in which balloons were carried to altitudes above 80,000 feet to test the resolution of targets painted on an RB-57 aircraft flying at various altitudes beneath the balloon;

3) A superpressure balloon, capable of maintaining a constant altitude without the use of ballast, carried a 300-pound pay load to an altitude of 100,000 feet. Superpressure balloons had earlier demonstrated the capability of carrying 80 pounds to 80,000 feet for flight durations of more than 30 days.

The 130 balloons launched in the 1964 program had diameters ranging from 100 to 250 feet. One major exception was the largest balloon ever fabricated which had a volume of 13.5 million cubic feet and a diameter of 332 feet. The average pay load lifted was 1,000 pounds; but many pay loads were more than 2,000 pounds. Most of the balloons were fabricated of polyethylene material. Balloons carrying the larger pay loads, however, were constructed of a mylar film with dacron fibers called scrim laminate. Some 12 flights were successfully performed with scrim balloons in 1964.

Among the important developments in balloon design and launch techniques was the development of a special launcher to be used aboard small ships, providing AFCRL with capabilities for launching balloons from locations all over the world. Another development was the successful flight of a balloon constructed of a new, extremely lightweight material consisting of two layers of polyethylene only .00014 inch thick, reinforced with a network of nylon filaments. This material, potentially, will give AFCRL the capability of carrying pay loads of about 100 pounds to altitudes above 150,000 feet.

In addition to balloon support for AFCRL programs in geophysics, meteorology, and astronomy, AFCRL supported seven balloon-carrier programs for the Air Force Systems Command, two for NASA, and one each for the AF Office of Scientific Research, OAR and the Defense Atomic Support Agency.

More than 50 per cent of the 130 balloons were launched from AFCRL's Balloon R&D Test Branch at Holloman AFB, New Mexico. About 40 per cent were launched from AFCRL's launch site at Chico, California. Others were launched from shipboard and at remote geographic locations. ★

AFCRL SCIENTISTS INITIATE YEAR-LONG, HIGH-ALTITUDE BALLOON FLIGHTS TO MEASURE STRATOSPHERIC MOISTURE

Aerospace Instrumentation Laboratory, AFCRL

Scientists of the Air Force Cambridge Research Laboratories, Office of Aerospace Research, have initiated a year-long series of high-altitude balloon flights to measure moisture in the stratosphere.

The program began in January with the two 87,000-foot altitude flights launched from AFCRL's balloon launch site in Chico, California. Each balloon was 150 feet long and carried scientific pay loads weighing 500 pounds. Configurations will vary in future flights.

Although the air at stratospheric altitudes contains only about .001 per cent water vapor, this water vapor has a profound effect on Air Force infrared sensors. Such sensors are used in many Air Force systems--satellite horizon seekers, reconnaissance systems, weather satellites, and so on.

Twenty-five vertical balloon flights are programmed for the year at the rate of 2 each month. In addition, five 11-day horizontal flights at float altitudes averaging 75 thousand feet will be made.

AFCRL scientists, as a result of these flights, hope to learn more about vertical and horizontal distributions of stratospheric humidity as well as seasonal variations. In addition to objectives relating to the design and performance of satellite infrared detectors, AFCRL scientists hope to learn more about correlations between moisture distributions and tropospheric weather systems.

This research program is one of several supported by the Air Force In-house Laboratory Independent Research Fund. The fund is a special category of resources used by AFCRL's Commander, at his discretion, to support urgent and timely research.

A highly improved, sensitive alpha radiation hygrometer is the key instrument being used in this investigation. The instrument consists of a source of alpha particles (Polonium 210), an improved thermoelectric (Peltier) cooler, Geiger counters, and a thermistor for measuring temperature changes.

It is sealed in a stainless steel cylinder 15 inches in diameter and 2 feet long. It is suspended 2,000 feet below the balloon system to prevent contamination by moisture carried aloft on the surface of the balloon.

Humidity measurements are made when the balloon descends from ceiling altitudes. It was found, in preflight tests, that more reliable measurements are made during balloon descent, rather than during ascent. During ascent, the sensitive hygrometer must pass through the moisture-contaminated environment created by the balloon.

In vertical soundings--as opposed to the 5 horizontal soundings--all data will be recorded onboard the recoverable system. At the conclusion of all vertical flights, a radio command from the Chico site separates the balloon from its pay load when it descends to a height of 30,000 feet. Pay loads are brought to earth suspended from a 40-foot parachute train.

Similar balloons of somewhat heavier polyethylene will be used for horizontal flights. They will be programmed to achieve constant float altitudes of about 75,000 feet, where they will remain aloft for 10 to 12 days. These flights will call for added ballast and batteries to increase pay-load weights to nearly 1,000 pounds.

Data from the horizontal flights will be gathered over thousands of miles while the platforms pass over a spectrum of mid-latitude tropospheric weather systems. Observations will be telemetered every two hours to the balloon control center at Chico, California, and to ground stations of the Federal Communications Commission network. They will carry the same type of sensor and complementary equipments as that carried on the vertical flights. The sensor, however, will not be suspended from below the balloon. Although, initially, contaminated

readings are anticipated (for two days of flight), a minimum of a week of uncontaminated data is expected to follow a drying-out period. Pay loads for horizontal flights will not be recovered when flights are ended.

Every measure has been considered to minimize moisture contamination. All components open to the atmosphere are made of nonabsorbing materials. Balloon ballast is baked and sealed. Closed components not used for sampling are hermetically sealed, and nylon reel-out line is used to lower the sensor below the balloon. The stainless steel container housing the hygrometer is equipped with venting systems for expelling any possible contaminants which may become present. Such contaminants will pass through a molecular sieve made of highly absorbent Zeolite in the venting process.

The novel and important program for measuring stratospheric humidity was conceived and directed by AFCRL scientists Norman Sissenwine, Donald Grantham, Henry Salmela, and Major Robert Cowne. The balloon systems for the vertical and horizontal flights, including telemetry deployment and flight-control equipment, were designed by Lewis Grass, Robert Bogart, and Ralph Cowie of the AFCRL Balloon Development Group. Launching and recovery operations were conducted by Captain Donald Cunningham and his airmen balloon specialists at the AFCRL Chico, California site. ★

radiation from an alternating-current nitrogen arc

P. W. SCHREIBER, Thermomechanics Research Laboratory, ARL

Researchers working with alternating-current arcs have the additional problem of time dependence. Quantities under study vary not only with experimental parameters, but also because of the cyclical fluctuations in the power supply. Many questions concerned with the experimental diagnostics or analysis of direct-current arcs have not been answered, and the complications introduced by time dependence make measurements and analytical calculations much more laborious. Thus, most arc research has been limited to investigations using d-c arcs. However, in conjunction with an in-house research program designed to investigate the energy-exchange process between cyclindrical arc columns and vortex flow fields, total radiation measurements were completed using alternating as well as direct current, and the time-dependent measurements were compared with approximate analytical results. The above research program is shown diagrammatically in Figure 1.

The facility for the study consisted of a gas vortex generator, water-cooled copper discharge tube with plane quartz windows, water-cooled copper electrodes, and an a-c or d-c power supply. The total arc length, stabilized by the vortex flow, was approximately 34 inches. The total mass flow rate of nitrogen could be varied from 0.001 to 0.125 pounds per second. Arc power was controlled by varying the coefficient of coupling between the primary and secondary of the input transformer. This control, in effect, placed a variable inductance in series with the arc which gives the required drooping voltage characteristic for electric-arc stabilization. (1)

Measurements included average and instantaneous radiant power, arc diameters, arc spectra, average arc transmittance, instantaneous and root-mean-square voltage and current, average arc power, and the arc time constant for various flow-field parameters such as total mass flow rate and vortex strength. A vacuum thermocouple was used to measure the average radiant power, and the calibration of this instrument was achieved by using two total radiation standards obtained from the National Bureau of Standards. Instantaneous radiant power was measured with a radiometer having a thermistor detector with a frequency response 10 times the fundamental of the radiation frequency. This radiometer was

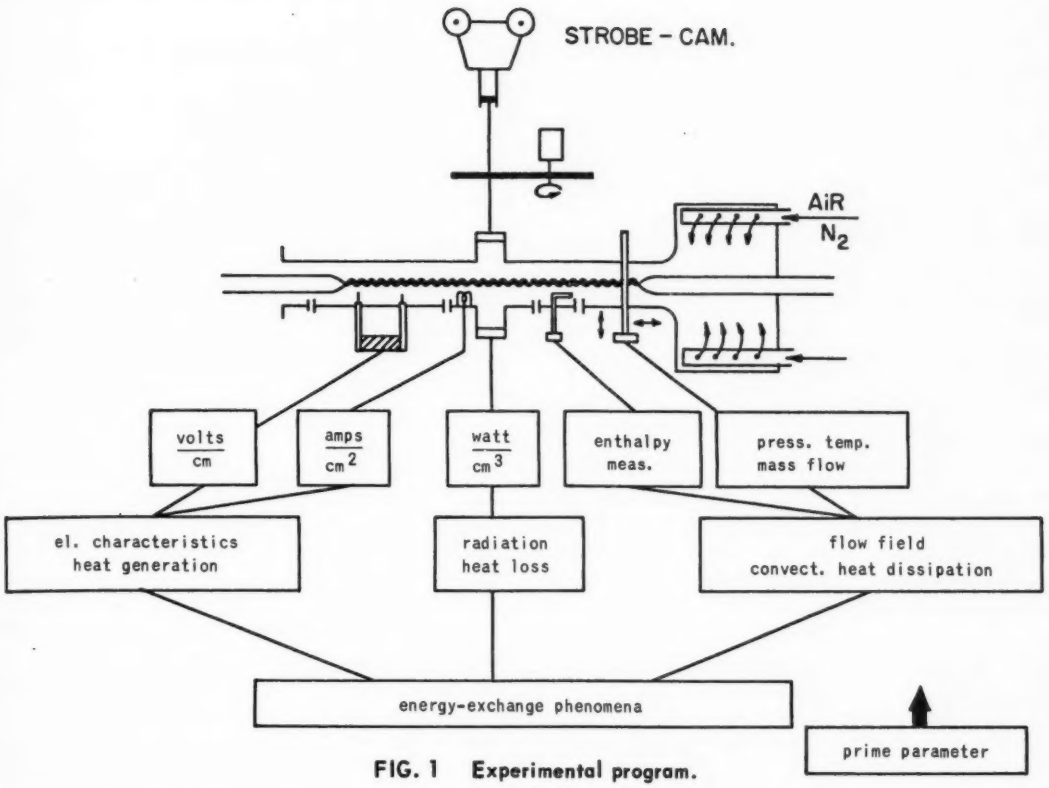


FIG. 1 Experimental program.

calibrated with a chopped secondary standard and also with a chopped black-body source. A chopper driven by a synchronous motor and phase shifter was used to obtain time-resolved photographs and spectra of the arc. Arc voltage and current were recorded with oscillographs and standard meters, and a Hall-type wattmeter was used to measure the average arc power.

The average power radiated from the arc column ranged from 4.4 per cent at an electrical-power input of 580 watts/cm to 10 per cent at a power input of 1200 watts/cm. Mass flow rate and vortex strength had little effect on the radiant power and, for a given power input, the radiant power was approximately the same for the a-c or d-c source. The average arc absorptance was too small to measure (measured arc transmittance was 1.01). Thus, the arc was assumed to be optically thin in calculating the total radiant power from measured quantities. The diameter (optical diameter which is approximately equal to the conducting diameter) of the arc remained almost constant throughout the electrical cycle, and the measured arc time constant (based on the decay of radiant energy) was approximately 1.5 milliseconds.

In addition to the above measurements, an approximate analytical solution of the alternating-current arc was obtained by using Kirchhoff's voltage law, the single fluid energy equation, Ohm's law and a number of assumptions. Block diagrams of these laws are, for an element of volume of the arc plasma,

$$\text{Power Stored} = \text{Electrical-Power Input} - \text{Stress Power} + \text{Radiant Power Absorbed}$$

$$- \text{Power Radiated} + \text{Net Power Conducted} + \text{Net Power Convected}$$

$$\text{Source Voltage} + \text{Arc Voltage} + \text{Inductor Voltage} + \text{Resistance Voltage} = 0$$

$$\text{Current Density} = \text{Electric-Field Strength} \times \text{Electrical Conductance}$$

The energy equation was simplified by introducing the heat-conductivity potential $\Phi = \int_0^T k(T)\, dT$ where ϕ is the integral of the thermal conductivity. In addition, the following assumptions were made: constant arc pressure, cylindrical symmetry, constant thermal diffusivity, no radial velocity, small constant axial velocity, axial electric field, no heat conduction in the axial direction, no absorption of radiant energy, electrical conductivity and the power radiated per unit volume are linear functions of the heat-conductivity potential, and no external resistance in the arc circuit. With these assumptions, the three equations were solved simultaneously by using an iteration technique, and equations for arc current, arc voltage, total radiation, heat-conductivity potential distribution, and arc radius were obtained as a function of time. In addition, an expression for the arc time constant was obtained. (2)

Although many assumptions were made in the approximate analytical solution, the calculated current, voltage, arc radius, and total radiation as a function of time are in reasonable agreement with the measured quantities. However, the calculated temperature distribution as a function of time appears to have a substantial error (approximately 10%). In general, the results are better than one would expect. Thus, there is a tendency for errors to compensate for each other in some cases. Before final conclusions can be made, the limits of error in the transport properties must be known. Hopefully, if turbulence is not important, a more refined solution with established transport properties would give better agreement with measured quantities. ★

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(1) *Andrada, T. and K. Erfurth, "An Experimental Investigation of a Vortex Stabilized Long Alternating-Current Arc Discharge," Proceedings of the First Plasma Arc Seminar, ARL 63-151, September 1963.*

(2) *Schreiber, P. W., "Radiation from an Alternating-Current Nitrogen Arc." AGARDograph 84, Part II, September 1964.*

12th annual Air Force Science and Engineering Symposium

The 12th Annual Air Force Science and Engineering Symposium will be held at the Aerospace Medical Division, Brooks Air Force Base, Texas, on 12-14 October 1965. It will be cosponsored by the Office of Aerospace Research (OAR) and the Air Force Systems Command (AFSC). OAR will play the part of the host.

The objectives of this annual symposium are to stimulate scientific and engineering growth within the Air Force scientific and engineering community, and provide an additional means for information exchange among the members of this community.

The program will reflect the full spectrum of science and engineering activities as carried out by the Air Force. These activities will include research, exploratory development and advanced development, system planning and analysis, system development, engineering, test and evaluation. Papers presented will be from among the best contributed and submitted in competition for the AFA Awards from the Centers, Divisions and Laboratories of OAR and AFSC, and from other appropriate elements of the Air Force. There will be both classified and unclassified meetings. And, for the first time in the history of the symposia series, dual sessions will be held at the same time. ★

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